Designation: D7914/D7914M – 14

Standard Test Method for Strength of Fiber Reinforced Polymer (FRP) Bent Bars in Bend Locations[1]

This standard is issued under the fixed designation D7914/D7914M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method determines the quasi-static ultimate strength of fiber reinforced polymer (FRP) composite bent bars commonly used as anchorages for stirrups in reinforced, prestressed, or post-tensioned concrete structures. This test method only applies to bars with a solid cross section.

1.2 FRP bent bars are often used in reinforced concrete applications to shorten the development length of the bar or to act as a tie or a stirrup to resist shear forces. Bent bars can be produced with varying angles of bend in order to fit their intended purpose.

1.3 For this test method, the FRP bars are bent at a 90 degree angle. In general, bars have a regular pattern of surface undulations, a coating of bonded particles, or both, that promote mechanical interlock between the bar and concrete.

1.4 The strength values provided by this method are short-term, quasi-static tensile strengths that do not account for sustained static or cyclic loading. If bars are to be used under high levels of sustained or repeated loading, additional material characterization may be required.

1.5 The characteristic values obtained from this test method are intended to represent the quasi-static ultimate strength of FRP bent bars with a tail length of twelve bar diameters.

1.6 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.6.1 Within the text, the inch-pound units are shown in brackets.

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

A615/A615M Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement
C39/C39M Test Method for Compressive Strength of Cylindrical Concrete Specimens
C143/C143M Test Method for Slump of Hydraulic-Cement Concrete
C192/C192M Practice for Making and Curing Concrete Test Specimens in the Laboratory
D792 Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement
D883 Terminology Relating to Plastics
D3171 Test Methods for Constituent Content of Composite Materials
D3878 Terminology for Composite Materials
D5229/D5229M Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials
D7205/D7205M Test Method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars
E4 Practices for Force Verification of Testing Machines
E6 Terminology Relating to Methods of Mechanical Testing
E122 Practice for Calculating Sample Size to Estimate, With Specified Precision, the Average for a Characteristic of a Lot or Process
E456 Terminology Relating to Quality and Statistics

3. Terminology

3.1 Terminology in D3878 defines terms relating to high-modulus fibers and their composites. Terminology in D883 defines terms relating to plastics. Terminology in E6 defines terms relating to mechanical testing. Terminology in E456 and in Practice E122 define terms relating to statistics and the selection of sample sizes. In the event of a conflict between

[1] This test method is under the jurisdiction of ASTM Committee D30 on Composite Materials and is the direct responsibility of Subcommittee D30.10 on Composites for Civil Structures.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

terms, Terminology in D3878 shall have precedence over the other terminology standards.

3.2 *Definitions:*

3.2.1 *bar, n*—a linear element, with a substantially round cross-section, often with surface undulations or a coating of particles that promote mechanical interlock with concrete.

3.2.2 *bend radius, n*—inside radius of the bend.

3.2.3 *bend strength, n*—ultimate tensile stress that can be carried by the FRP bent bar provided that failure occurs in the bend.

3.2.4 *bent bar, n*—a bar with a section formed in such a manner as to deviate from its primary axis.

3.2.5 *equivalent bar diameter, n*—the equivalent bar diameter is determined according to Test Method D7205/D7205M and is based upon the standard cross-sectional area of the FRP bar.

3.2.6 *quasi-static, adj*—loading where inertial effects (time and inertial mass) are irrelevant.

3.2.7 *standard cross-sectional area, n*—the cross-sectional area of a standard numbered steel concrete reinforcing bar as given in Specification A615/A615M, Table 1, and based upon a circular cross section and determined over at least one representative length.

3.2.8 *stirrup, n*—a bar shape comprised of one or more bent bars used to resist shear forces in reinforced concrete.

3.2.9 *tail length, n*—the length provided beyond the bend portion of a bent bar.

3.2.10 *tensile strength, n*—ultimate tensile strength of FRP bars in the direction parallel to the fibers.

3.3 *Symbols:*

3.3.1 A—standard cross-sectional area of a single leg of the FRP bent bar determined according to Test Method D7205/D7205M, mm^2 [in.^{2}]

3.3.2 CV—sample coefficient of variation, in percent

3.3.3 d_b—effective bar diameter taken as the equivalent bar diameter determined according to Test Method D7205/D7205M and is based upon the standard cross-sectional area of the FRP bar, mm [in.]

3.3.4 F_{fu}—ultimate tensile strength parallel to the fibers determined according to Test Method D7205/D7205M, MPa [psi]

3.3.5 F_{fb}—ultimate bend strength of the FRP bent bar, MPa [psi]

3.3.6 L_t—tail length of the FRP bent bar occurring after the bent portion of the bar, mm [in.]

3.3.7 n—number of specimens

3.3.8 P_{fb}—ultimate force capacity of the FRP bent bar, N [lb]

3.3.9 r—repeatability limit, the value below which the absolute difference between two individual test results obtained under repeatability conditions may be expected to occur with a probability of approximately 0.95 (95 %)

3.3.10 r_t—inside radius of the bent portion of an FRP bent bar, mm [in.]

3.3.11 S_{n-1}—sample standard deviation

3.3.12 χ—percentage of the guaranteed tensile strength of the straight portion of the bar that is retained in the bend location

3.3.13 x_I—measured or derived property

3.3.14 $\bar{x}$—sample mean (average)

4. Summary of Test Method

4.1 One or more FRP bent bars, cast into two blocks of concrete, are loaded in tension until failure occurs at the bent portion of the bar. An actuation device is placed in between the two concrete blocks so that the blocks are forced apart, inducing tension on the FRP bent bar.

4.2 Force is recorded throughout the test.

4.3 The principal variables used in the tests are the cross-sectional area, bend radius, and type of FRP bent bar.

5. Significance and Use

5.1 This test method is intended to determine the bend strength developed at a standard twelve bar diameters of embedment and the strength reduction factors of FRP bent bars that are typically used as anchorages in concrete. From this test, a variety of data are acquired that are needed for design purposes. Material-related factors that influence the tensile response of bars and should therefore be reported include the following: constituent materials, void content, volume percent reinforcement, methods of fabrication, and fiber reinforcement architecture. Similarly, factors relevant to the measured tensile response of bars include specimen preparation, specimen conditioning, environment of testing, specimen alignment, and speed of testing. Properties, in the test direction, that may be obtained from this test method include:

5.1.1 Ultimate bend strength of the FRP bent bar and

5.1.2 Percentage of the guaranteed tensile strength of the straight portion of the bar that is retained in the bend location.

5.2 The results may be used for material specifications, research and development, and structural design and analysis.

NOTE 1—Two FRP bends are tested simultaneously in this test method, but in some cases only one bend may rupture. While resulting in a valid failure, notice should be taken that only one bend has been effectively measured and that the final compiled test results using this method could differ from those resulting from single FRP bend testing.

6. Interferences

6.1 The results from the procedures presented are limited to the material and test factors listed in Section 5.

6.2 *Loading Provisions*—The test is completed using a hydraulic jack that exerts equal and opposite forces onto two concrete blocks. The block containing the test section of the FRP bent bar must be free to translate so that force exerted on the bent bars can be accurately measured. Bending of the bent bars during casting of the concrete or testing of the specimen may cause premature failure outside of the bend. Every effort shall be made to minimize bending and uneven loading of the bent bars.

6.3 *Bend Geometry*—In this test standard, the bend in the FRP bar comprises a 90 degree change of direction with a constant radius of curvature through the bend. Bends other than 90 degrees may produce different test results, and are not covered by this standard.

6.4 *Measurement of Actual Cross-Sectional Area*—The actual cross-sectional area of the bar is measured by immersing a prescribed length of the specimen in water to determine its buoyant weight. Bar configurations that trap air during immersion (aside from minor porosity) cannot be assessed using this method. This method may not be appropriate for bars that have large variations in cross-sectional area along the length of the bar.

6.5 *Variation Tolerance Between Actual and Standard Cross-Sectional Area*—All specimens shall have an actual cross-sectional area that varies no more than +20% and -0% from the bar's standard cross-sectional area

6.6 *Specimen Handling*—During the handling and preparation of specimens, all deformation, heating, outdoor exposure to ultraviolet light, and other conditions possibly causing changes to material properties of the specimen shall be avoided.

7. Apparatus

7.1 *Hydraulic Cylinder*—The hydraulic cylinder shall have force capacity in excess of the capacity of the specimen, and be capable of applying force at the required loading rate. Hand operated testing machines, electro-mechanical cylinders, or motorized pumps having sufficient volume in one or more strokes to complete a test may be used if they satisfy the loading provisions in 11.2.6.

7.2 *Force Indicator*—The testing apparatus force-sensing device (a load cell or similar) shall be capable of indicating the total force being carried by the specimen. This device shall be essentially free from inertia-lag at the specified rate of testing and shall indicate the force with an accuracy over the load range(s) of interest of within ± 1% of the indicated value, as specified by Practices E4.

7.3 *Environmental Test Chamber*—An environmental chamber is required for conditioning and test environments other than ambient laboratory conditions. These chambers shall be capable of maintaining the required relative temperature to within ±3°C [±5°F] and the required relative humidity level to within ±5% RH. In addition, the chambers may have to be capable of maintaining environmental conditions such as fluid exposure or relative humidity during the conditioning and testing.

7.4 The test set-up, shown in Fig. 1, consists of a hydraulic jack to distribute the applied force to the surface of the concrete. A plywood bearing pad 200 mm square and at least 6 mm deep [8 in. square and 0.25 in. deep] in conjunction with steel spreader plates 100 mm square and 6 mm deep [4 in. square and 0.25 in. deep], or similar provisions shall be used at the end of the actuator to spread the force on the concrete blocks and minimize bending forces on the bent bars. Hydraulic cylinder shall be placed in the same plane as the FRP bars, and shall be centrally located between the legs (± 6mm [0.25 in.]). The block containing the test section of the bar shall be placed on top of steel rollers to minimize the friction forces between the block and testing bed. When moving the specimens, special care shall be taken to avoid damaging or displacing the cast FRP bars.

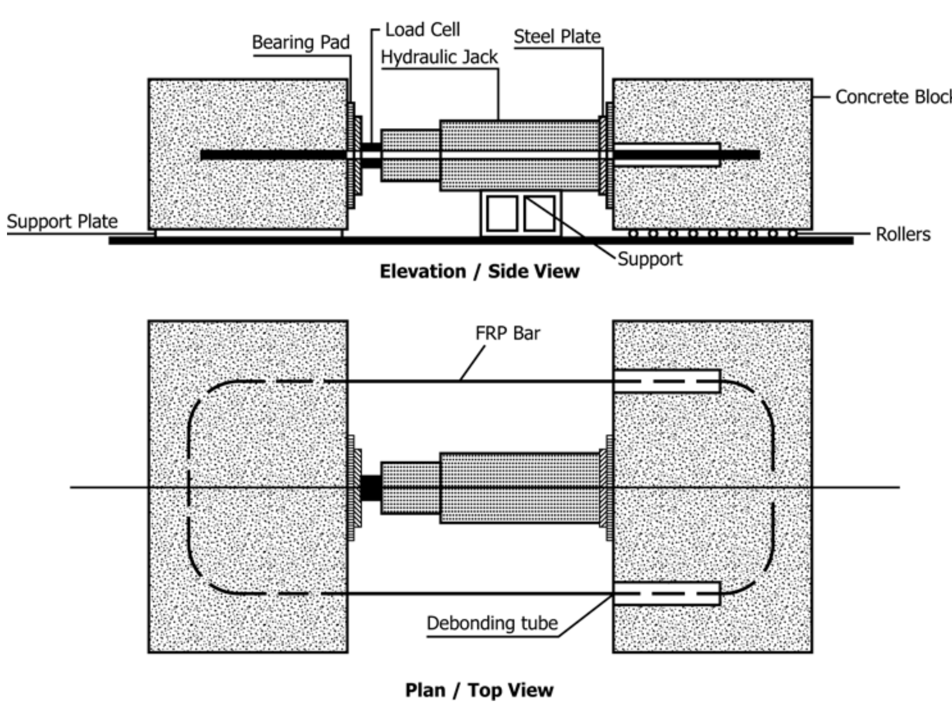

FIG. 1 Test Setup